

MICROCOPY RESOLUTION TEST CHART NATIONAL BUREAU OF STANDARDS-1963-A 780767

AD-A134 988

# APPLICATION OF RAPIDLY SOLIDIFIED ALLOYS

A. R. Cox United Technologies Corporation Pratt & Whitney Aircraft Group Box 2691, West Palm Beach, Florida 33402

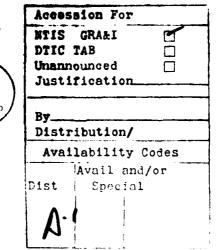
August 1978

Quarterly Report for Period 1 May 1978 through 1 August 1978

Approved for public release, distribution unlimited.

Sponsored by Defense Advanced Research Projects Agency

Prepared for Air Force Materials Laboratories Wright-Patterson AFB, Ohio 45433



The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the Advanced Projects Agency or the U.S. Government

### UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Date Entered)

REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 2. GOVY ASCESS	3. RECIPIENT'S CATALOG NUMBER
FR-10754 AI34 7	<i>[ ]</i>
4. TITLE (and Subtitle)	5. TYPE OF REPORT & PERIOD COVERED
ALLOVO	Quarterly Report  1 May 1978 — 1 August 1978
APPLICATION OF RAPIDLY SOLIDIFIED ALLOYS	6. PERFORMING ORG. REPORT NUMBER
	FR-10754
7. AUTHOR(s)	8. CONTRACT OR GRANT NUMBER(a)
A. R. Cox T. D. Tillman	F33615-76-C-5136
R. J. Patterson	ļ
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
United Technologies Corporation	AREA & WORK UNIT NUMBERS
Pratt & Whitney Aircraft Group Government Products Division	
Box 2691, West Palm Beach, Florida 33402	
11. CONTROLLING OFFICE NAME AND ADDRESS Defense Advanced-Research Projects Agency	12. REPORT DATE August 1978
1400 Wilson Boulevard	13. NUMBER OF PAGES
Arlington, Virginia 22209 (Dr. E. C. vanReuth)	31
14. MONITORING AGENCY NAME & ADDRESS(II different from Controlling O	ffice) 15. SECURITY CLASS. (of this report)
Air Force Materials Laboratories Wright-Patterson Air Force Base, Ohio 45433	UNCLASSIFIED
(Mr. A. Adair)	15a. DECLASSIFICATION/DOWNGRADING
	SCHEDULE
Approved for Public Release, Distribution Unlimited	
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if differ	rent from Report)
18. SUPPLEMENTARY NOTES	
19. KEY WORDS (Continue on reverse side if necessary and identify by block n	iumber)
Powder Metallurgy, Rapid Solidification, Centrifugal Atomiza Iron Alloys	ation, Convective Cooling, Aluminum Alloys,
20 ABSTRACT (Continue on reverse side if necessary and identify by block no	umber)
This program is being conducted for the purpose of apply aluminum and iron alloy powders and subsequent development application (Al alloys) and higher speed bearing material (Fe convective cooling are being used to produce the fast cooled possible.	of stronger alloy compositions for fan blade alloys). Centrifugal atomization and forced

UNCLA	ASSIFIED
SECURITY CLASSIFICA	ATION OF THIS PAGE(When Date Entered)
Both Al and Fe all	eport period, adaptation of the RSR process to aluminum and iron systems was begulloys were produced and the Fe alloys were consolidated by direct extrusion. Heat tress testing were used for preliminary evaluation of iron alloys.

L

UNCLASSIFIED

#### SUMMARY

This program is being conducted for the purpose of applying the principle of rapid solidification to aluminum and iron alloy powders and subsequent development of stronger alloy compositions for fan blade application (Al alloys) and higher speed bearing material (Fe alloys). Centrifugal atomization and forced convective cooling are being used to produce the fast cooled powder.

During this report period, adaptation of the RSR process to aluminum and iron systems was begun. Both Al and Fe alloys were produced and the Fe alloys were consolidated by direct extrusion. Heat treat study and hardness testing were used for preliminary evaluation of iron alloys.

# TABLE OF CONTENTS

Section		Page
	LIST OF ILLUSTRATIONS	v
	LIST OF TABLES.	vi
I	INTRODUCTION	1
П	POWDER MECHANICS	2
Ш	MATERIAL SELECTION	7
IV	CONVERSION AND CONSOLIDATION	9
V	MATERIAL EVALUATION	12
VI	ON-GOING STUDY	27

# LIST OF ILLUSTRATIONS

**CR.C.** 52.25 5.25

Figure		Page
1	AGT 500000 Laboratory Scale Rapid Solidification Rig	2
2	Partial Sieve Analysis of XSR/RSR Powder	4
3	Particle Size Completely Solidified Before Impacting XSR Tank Wall as Function of Speed	5
4	Predicted Mean Cooling Rates vs Particle Size (XSR/RSR)	5
5	B-1, EB Weld No. 4, Penetration 0.046 in. (0.117 cm)	13
6	Surface Appearance of 90 $\mu m$ XSR and RSR 7075 Aluminum Powder	14
7	Microstructure of 90 μm XSR and RSR 7075 Aluminum Powder	15
8	Microstructure of 62 μm XSR and RSR 7075 Aluminum Powder	16
9	Representative Microstructure of Iron Alloy Buttons, as EB Welded: a and b Penetration of 0.004 in. (0.010 cm); c and d Penetration of 0.008 in. (0.020 cm)	17
10	Microstructure of RSR 200 Iron Alloy Powder	19
11	Representative Microstructure of Iron Alloy Extrusions	20
12	Representative Microstructures of Iron Alloy Extrusions, Solutioned and Quenched	22
13	As Quenched Hardness vs 10 Min Solution Temperature	24
14	Hardness vs Solution Temperature	25
15	Typical Microstructure of Alloy 203C Fully Heat Treated	26

# LIST OF TABLES

Figure		Page
1	First Al and Fe Matrix	7
2	Experimental Alloy Composition	8
3	Powder Runs Attempted During 1st Quarter	10
4	Composition of Alloys Converted to Powder	11
5	Iron Alloy Extrusions	11
6	Iron Alloy Button Hardness	18
7	First Iron Matrix Extrusion and Heat Treat Identification Scheme	21
8	Hardness of As Solutioned Steel	23

200

#### SECTION I

#### INTRODUCTION

Rapid solidification of metal alloys has shown that distinct and dramatic changes in microstructure and crystal form can be attained beyond those possible by any known method of conventional solidification. These results are recognized by experts throughout the field of metallurgy as a means to achieve major improvements in metal strength, environmental compatibility, electrical properties, etc. Through the use of fast cooling, the following appears to be eminently possible: (1) stronger and more corrosion resistant steels because of improved homogeneity and (2) a new breed of aluminum, copper, and nickel alloys because of improved secondary phase dispersion.

An ARPA sponsored program with the Pratt & Whitney Aircraft Group, Government Products Division (P&WA/Florida), has shown that by using the P&WA RSR process and equipment, it is possible to achieve rapid solidification in spherical powder under conditions which depict steady-state operations commensurate with production rates in excess of 1400 tb/hr. Further, this program has demonstrated that concurrent high product quality can be achieved and the resulting powder metal is in a form which can be readily handled and processed into useful shapes for subsequent application. No other method known to achieve similar rates of solidification can lay claim to these combined achievements.

The program has gone even further since it has demonstrated that controlled, rapid solidification can lead to a microcrystalline form, a condition which could possibly point the way to alloy homogeneity never before considered possible. It has also shown that a central rotary source can be used for liquid metal atomization into powder particles of sizes commensurate with average particle cooling rates of 10\*-10\*oK/sec.

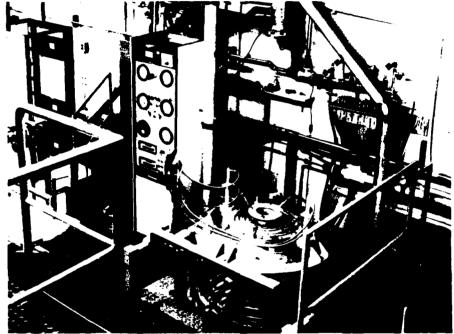
This program is a modification to the Advanced Research Project Agency (ARPA) sponsored work which is directed toward superalloy development. Its purpose is to expand the scope of work in the field of rapid solidification from the exclusive study of superalloys to a study of aluminum, and iron base alloys. The specific objectives of this added effort are the development of an improved aluminum alloy suitable for V/STOL-A fan blades and an improved iron alloy suitable for rolling element bearings for advanced aircraft powerplants.

The program is a 36-month effort which begins with adaptation of the rapid solidification rate process to Al and Fe alloy systems and terminates with a payoff analysis of new materials as adapted to V/STOL-A and F100 advanced engine derivative requirements. This is the first technical report and covers the first through the third months of the program. It deals with adaptation of RSR processing to Al and Fe systems and the subsequent evaluation of these alloys.

#### SECTION II

#### **POWDER MECHANICS**

Pratt & Whitney Aircraft has constructed a scaled down RSR powder device, designated AGT 500000 and shown in Figure 1. It is being used to produce rapidly solidified powder for this program. The new unit is similar to AGT 400000 (the rig now used for superalloy rapid solidification studies). The AGT 500000 device is based on vacuum (or inert gas) induction melting of small charges of metal (up to 14 lb based on iron) and centrifugal atomization from a central, high speed rotary atomizer, Figure 1.



FAE 163569

Figure 1. AGT 500000 Laboratory Scale Rapid Solidification Rig

Forced gas (helium) convective cooling is used to produce the desirable rapid solidification with resulting spherical particles, as opposed to splats generated by conductive cooling. Rotary atomizer design, speed, and melt superheat control particle size, velocity, and trajectory; with the main factors controlling rapid solidification being the heat transfer coefficient and particle size.

With respect to heat transfer, our analytical models show that film heat transfer coefficients on the order of  $2 \times 10^6$  Btu/ft²/hr/°F (14.7  $\times$  106 cal/cm²/sec/°C) are indicative of infinity for particles greater than 20 microns in diameter. Forced convection of the type used in the AGT 500000 rig can achieve film coefficient values about two orders of magnitude less than this ideal case.

During this report period, effort was directed toward characterization of Al powder made in the AGT 500000 device. Iron base powder will be characterized at a later date. Runs made in the AGT 500000 device have been designated "XSR" to distinguish them from runs made in the larger AGT 400000 device used in the RSR program. Figure 2 presents partial sieve analyses of aluminum alloy 7075 made under RSR conditions; a Co-modified 7075, XSR 33; and of a typical

RSR size distribution for nickel base superalloys, shown for comparative purposes. Size analysis of the aluminum powder finer than -140 mesh was not conducted since that fraction is generally retained for other studies, such as consolidation and extrusion. It should be noted that mechanical failure prevented completion of the XSR run, resulting in the generation of a substantial amount of material above -140 mesh as the turbine speed decreased from the desired operating point of 35,000 rpm. This, of course, also implies that a smaller yield of -140 mesh material was obtained than would normally occur.

Figure 3 presents the maximum velocity that an Al 2024 particle of a given size may have if the particle is to be completely solidified prior to impact with the wall of the XSR device; the two curves display the effect of different amounts of superheat. Al 2024 was selected for this theoretical study of solidification under RSR/XSR conditions because of the limited availability of thermal data at hand for aluminum alloys at the time of the study, and because the aluminum-copper system has been used by others for the characterization of rapid solidification splat quenching devices.

It is interesting to compare the predictions of Figure 3 with the results presente.

2. At 35,000 rpm the tangential velocity of the atomizer is approximately 105 m/sec, speed the largest particle of Al 2024 which can completely solidify prior to impact should impact while molten, adhering to the wall. Yet, the sieve analysis of XSR 33 indicates that a significant amount of substan material was obtained.

Several factors account for this apparent discrepancy: (1) recently acquired thermal data for 7075 indicate that near the melting point the specific heat is only 50 to 60% that of 2024, larger particles of 7075 will solidify before impact, for a given velocity; (2) the XSR melt contained somewhat less superheat than was used for the theoretical work; (3) some of the superheat contained in the melt was lost during the transfer and atomization process (e.g., to the watercooled atomizer); the theoretical study assumed that particles contained the specified superheat at the time of formation; (4) the graph presents a limit for the sizes of particles which are completely solidified at impact, while in reality, partially solidified particles might be sufficiently solid that they do not adhere to the wall; (5) thermal data for the alloys of interest to this program have not been found for the liquid state, and these properties had to be estimated for the theoretical effort. In this regard, data recently found for pure aluminum suggest that the specific heat of molten materials is somewhat lower than we have estimated, so that cooling rates (and distances required for solidification) resulting from the calculations is probably somewhat conservative; (6) some of the material larger than 140 mesh may have been formed by splashing of the melt as it continued to pour after the turbine drive ceased rotation. Also, as noted earlier, much of the material probably formed as the turbine speed decreased from 35,000 rpm. These particles would not only have velocities lower than 100 m/sec, but from earlier work in the RSR program, they would also be larger. Simple extrapolation of the curves of Figure 3 suggests that particles at least as large as 650 microns diameter may solidify completely prior to impact when speeds are on the order of 1 m/sec (334 rpm for XSR 33). Indeed, less than 3% of the particulate collected from the run was larger than 40 mesh (425 microns).

Theoretical and empirical efforts were also undertaken to attempt to determine the cooling rates of materials produced in the XSR device. The theoretical work for mean cooling rates is presented in Figure 4 for systems of interest to this program; the curve previously published for IN 100 is shown for comparison. As noted for the previous figure, the data recently acquired for the specific heat of 7075 and for the probable behavior of the specific heat above the liquidus would suggest that the mean cooling rate of 7075-type alloys is probably somewhat better than the curves presented for both 2024 and pure aluminum, the specific heats of which are similar. How well the cooling rates predicted for 347 stainless steel correlate with those which might be obtained for compositions contemplated for bearing elements is not presently known.

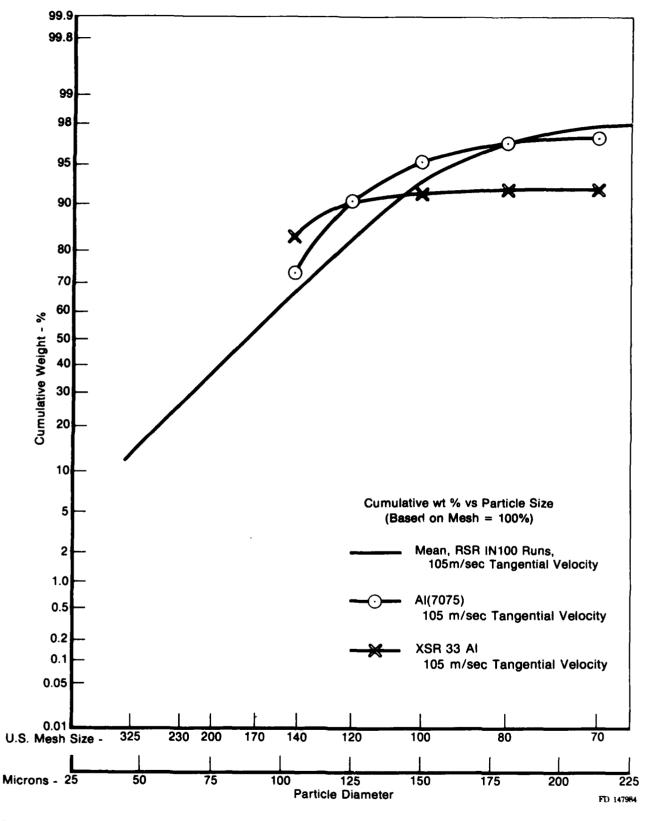


Figure 2. Partial Sieve Analysis of XSR/RSR Powder

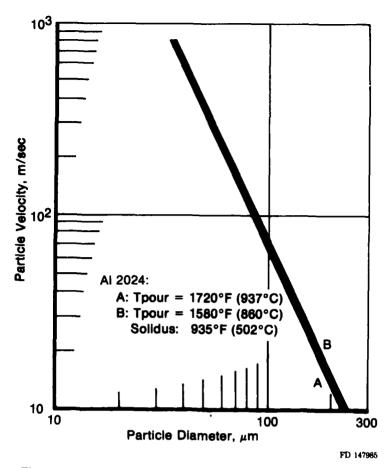


Figure 3. Particle Size Completely Solidified Before Impacting XSR Tank Wall as Function of Speed

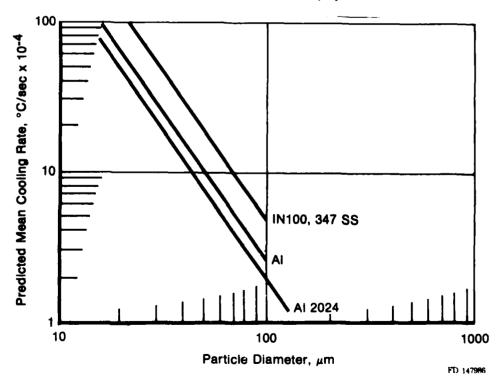


Figure 4. Predicted Mean Cooling Rates vs Particle Size (XSR/RSR)

The empirical side of this effort has not fared as well, and no results can be presented at this time. First, as reported by Horwath and Mondolfo¹ for the Al-Cu system, and as discussed by Holiday² et al for some of the nickel base su ralloys, the secondary dendrite spacing commonly used for empirical determination of cooling rate has been found to depend not only upon cooling rate of the material but also upon its specific chemistry. Hence, while the method may allow the relative comparison of cooling rates for particles of a specific composition, the technique does not appear to allow the independent determination of absolute rates. Second, metallographic analysis of particles of the steel and aluminum alloys prepared to date has yielded structures which are not classically dendritic, so the technique has not even allowed the determination of relative rates for these alloys. An attempt to obtain a feeling for the relative rates by microprobe determination of the variation of segregation within particles of different sizes is also futile, since the beam size of the microprobe is at least as large as any such segregation.

Horwath, J. A., L. F. Mondolfo; "Dendritic Growth"; ACTA Met, Vol 10, 1962, pp. 1037-1042.

<sup>&</sup>lt;sup>2</sup> Holiday, P. R. et al; Rapid Solidification Effects on Alloy Structures; Rapid Solidification Processing, Claitor's Publishing Division, Baton Rouge, 1978.

#### SECTION III

#### **MATERIAL SELECTION**

Two matrices, one each for Al and Fe systems, were formulated as listed in Table 1 and selections were made for production of vacuum melt ingots suitable for conversion to powder.

TABLE 1. FIRST Al AND Fe MATRIX

_		All	latrix	*		
		. <u>c</u>	obalt		_	
	Zn-	0.8	1.6	2.4	3.2	
	5.6	X	X		X	
	7.0	X			x	
	8.4		X			
	9.8					
		Fe N	latrix	*		
		Moly	bdenum	1		
Cr	C	2	4	6	8	
	0.8	(	( <b>M</b> -50)			
4	0.8					
9	0.8 0.95					
14	0.8 1.1	(EX-0007) X		x		
19	0.8 1.25	x			x	

In the aluminum matrix, Zn and Co were varied using similar or greater amounts of Zn than specified in 7075 and varying Co from 0.8 wt% to 3.2 wt%. The Co forms a Co<sub>2</sub>Al<sub>6</sub> compound which, when present in an appropriate dispersion, should control grain size since it is insoluble at the solutioning temperatures of the Zn, Mg, and Cu rich phases. Increasing Zn will provide a greater amount of second phase available for precipitation hardening. One heat of 7075 was run as a control to assess the effects of rapid solidification on a high-strength, age-hardenable alloy.

\*Amounts are in weight %.

Four selections were made from the Fe matrix which contain high Cr, 14 and 19 wt%, and varying amounts of Mo. One alloy similar to EX-00007 was included for comparison with other work being done on this alloy.

Both Fe and Al experimental alloy samples in the form of buttons weighing 2 oz (60g) for Fe and 1 oz (30g) for Al have been produced. These alloys, listed in Table 2, have been treated by electron beam (EB) surface irradiation to produce macroregions depicting rapid solidification. Difficulty was encountered in melting elements to produce the Al buttons. Two methods were tried, a tungsten arc melting device used to make small experimental samples and an induction furnace with melting taking place in a small ceramic crucible. Neither method was successful in completely alloying all elements. Additional trials will be made using the induction furnace and forced mixing to ensure complete alloying of all elements. Iron alloys were produced in the arc melting device and no problems were encountered in obtaining proper alloying.

TABLE 2. EXPERIMENTAL ALLOY COMPOSITION\*

Identification Number	c	Мо	Cr	v	Mn	Si	Fe
BI-1	0.8	2.0	4.0	1.0		_	Bal
BI-2	0.8	4.0	4.0	1.0	_	_	Bal
BI-3	0.8	8.0	4.0	1.0	-	_	Bal
BI-4	0.8	2.0	9.0	1.0	_	_	Bal
BI-5	0.8	6.0	9.0	1.0	_	_	Bai
BI-6	0.95	2.0	9.0	1.0	_	_	Bal
BI-7	0.95	6.0	9.0	1.0	_	_	Bal
BI-8	0.8	6.0	14.0	1.0	_	_	Bal
BI-9	1.1	2.0	14.0	1.0	_	-	Bal
BI-10	1.1	6.0	14.0	1.0		_	Bal
BI-16A	1.1	2.0	14.0	1.0	0.2	0.2	Bal
BI-16B	1.1	2.0	14.0	1.0	0.2	_	Bal
BI-17A	1.1	6.0	14.0	1.0	0.2	0.2	Bal
BI-17B	1.1	6.0	14.0	1.0	0.2	_	Bal
BI-18A	1.25	2.0	19.0	1.0	0.2	0.2	Bal
BI-18B	1.25	2.0	19.0	1.0	0.2	_	Bal
BI-19A	1.25	8.0	19.0	1.0	0.2	0.2	Bal
BI-19B	1.25	8.0	19.0	1.0	0.2	_	Bal

Note: BI 5.6% Zn, 0.8% Co, 2.5% Mg, 1.0% Cu, Bal Al \*wt.%

#### SECTION IV

#### **CONVERSION AND CONSOLIDATION**

Twenty powder runs were attempted during the first quarter to gain experience in operation of AGT 500000 and to provide material for evaluation. Atomizer speed, nozzle diameter, cup radius, and pour temperature were varied to assess their impact on powder yield. Some difficulties were encountered and are under investigation to assure the best possible yield of -140 mesh (105 micron) powder. Tables 3 and 4 give material compositions and pertinent information and comments on the twenty powder conversions attempted.

XSR-24 was the first steel conversion attempted in a redesigned high temperature furnace with the result being no metal flow due to nozzle plugging, presumably due to the nozzle temperature being too low. This furnace has been redesigned again and incorporates a separate transfer tube heater and should be operational in the second quarter of this contract.

Five RSR steel conversions were attempted with four being successful; the one failure being due to a run abortion after observing abnormal appearance of metal leaving the cup. Initial indications are that iron base alloys must be converted at a lower superheat than nickel base alloys to achieve stable melt flow on the atomizer rotor.

Fourteen XSR A1 conversions were attempted with ten being successful and six having yields in excess of 50%. Two runs XSR-26 and 28 did not pour due to a nozzle blockage and insufficient superheat respectively.

Both the Al and Fe alloys were screened in air through -80 mesh and -140 mesh screens. The -140 mesh powder was then outgassed, and the cans were filled and sealed under vacuum. Cans were fabricated of 6061 for the Al powder and 304 stainless steel for the Fe powder.

Three extrusion temperatures 1750°F (954°C), 1850°F (1010°C), and 2000°F (1093°C) were used on the four Fe compositions (three cans each). Reduction ratio was 15:1 through a ceramic insert in a steel die with a 90° included angle steel cone being used in front of the die. Final diameter was a nominal 0.75 in. (1.9 cm). Table 5 gives particulars on each extrusion.

Six Al extrusion cans were prepared, three cans of XSR 19, 20, and 21 combined, and one can each of XSR 23, 25, and 27. These cans have been shipped to AFML and should be extruded in the second quarter of this contract.

POWDER RUNS ATTEMPTED DURING 1ST QUARTER TABLE 3.

VM 678	XSR-Run		Nozzle Dia	Çmb	Cup Radius	Nozzle	Melt	Alloy Melting	Percent	
VM 678         0.135         24K         3.125         1180         1680	No.	Alloy	m. (cm)	Speed (rpm)	m. (cm)	Temp 'r ('C)	Lemp 'F ('C')	Foint 'F ('C)	Yield	Comments
VM 678         (0.318)         24K         (7.858)         (889)         (882)         (689)         (882)         (789)         (889)         (789)         (889)         (789)         (889)         (789)         (889)         (789)         (889)         (789)         (889)         (789)         (889)         (40.7         (40.7)         (40	XSR-19	VM 678	0.125	24K	3.125	1290	1620	1180	36.4	
VM 578         0.12b         24K         3.12b         1180         1460         1810         38.9           VM 578         0.12b         24K         7.32b         (180)         (780)         (180)         40.7           VM 581         0.12b         24K         3.12b         1180         1460         1180         40.7           VM 581         0.12b         24K         7.32b         1180         1460         1180         40.7           VM 581         0.12b         24K         7.32b         1177         (627)         75.2         No helium flow           VM 582         0.12b         24K         7.38b         120         1250         26.0         No helium flow           VM 582         0.12b         24K         1.32b         1180         1460         1180         0         No helium flow           VM 582         0.12b         24K         1.32b         1180         1560         1180         0         No helium flow           VM 583         0.12b         24K         3.12b         1180         1560         1180         0         No helium flow           VM 584         0.12b         24K         3.12b         1180         1180			(0.318)		(7.938)	(669)	(883)	(638)		
VM 678         (0.318)         (7.834)         (7.854)         (684)         (778)         (683)         40.7           VM 671         (0.318)         4.6         1.269         1.600         1.400         1.63         40.7           VM 671         (0.318)         24K         3.128         1.160         1.490         1.63         0.0           VM 671         (0.318)         24K         3.128         1.170         1.490         1.62         0.0           VM 672         (0.318)         24K         5.250         —         2800         0.75         0.0           VM 672         (0.318)         24K         5.250         —         2800         0.74         0.0           VM 672         (0.100)         30K         3.500         1.20         1.60         0.0	XSR-20	VM 578	0.125	24K	3.125	1180	1480	1180	33.9	
VM 678         0.136         24K         3.125         1100         1400         1180         40.7           VM 681         (0.218)         24K         3.125         1160         1430         (189)         0.77           VM 681         (0.128)         24K         3.125         1160         1430         1180         0.07           VM 681         (0.1284)         24K         3.125         1177         (627)         0.00         0.00           VM 682         (0.1284)         24K         6.260         -         2820         2800         15.2           VM 682         (0.128)         360         1220         1180         0.00         No helium flow           VM 682         (0.100         3K1         3.125         1180         1180         0.00         No helium flow           VM 683         (0.1284)         24K         3.125         1180         1180         0.00         No helium flow           VM 683         (0.1284)         24K         3.125         1180         1440         0.00         No helium flow           VM 684         (0.128)         24K         3.125         1180         1460         0.00         No helium flow			(0.318)		(7.938)	(889)	(783)	(838)		
VM 681         -(0.316)         <	XSR-21	VM 678	0.125	24K	3.125	1100	1400	1180	40.7	
VM 681         (0.128)         24K         3.125         1160         1430         1180         0         No helium flow of cash           VM 681         (0.128)         24K         3.125         1160         1430         1180         75.2           VM 682         (0.124)         24K         7.288         (827)         2600         0         No helium flow of cash           VM 682         (0.124)         (1.33.36)         (1.33.36)         (1.428)         (1.427)         74.8         Nozzle of cash           VM 682         (0.100)         30K*         3.800         1220         1180         0         Nozzle of cash           VM 682         (0.124)         (1.428)         (1.427)         (1.427)         (1.427)         Nozzle of cash           VM 683         (0.124)         (1.428)         (1.428)         (1.427)         (1.428)         (1.427)           VM 683         (0.124)         (1.428)         (1.428)         (1.427)         (1.428)         (1.427)           VM 684         (0.124)         (1.428)         (1.428)         (1.427)         (1.428)         (1.427)           VM 685         (0.124)         (1.288)         (689)         (1.428)         (1.427)         (1.489) <td></td> <td></td> <td>(0.318)</td> <td></td> <td>(7.938)</td> <td>(993)</td> <td>(180)</td> <td>(838)</td> <td></td> <td></td>			(0.318)		(7.938)	(993)	(180)	(838)		
VM 681         (0.318)         (7.28)         (827)         (777)         (827)         75.2           VM 682         (0.254)         24K         (7.898)         (827)         (770)         (827)         75.2           VM 682         (0.125)         24K         (7.898)         (822)         (810)         627)         74.8           VM 682         (0.1264)         (1.254)         (1.277)         (1.477)         (1.477)         74.8           VM 682         (0.1264)         3.00C         1.125         1.136         1.186         0         Norate blocked           VM 683         (0.1264)         24K         (7.189)         (689)         (1.883)         1.186         0         Norate blocked           VM 683         (0.1264)         24K         (7.189)         (689)         (1.890)         (1.890)         0         Norate blocked           VM 686         (0.1264)         24K         (7.189)         (689)         (680)         (1.800)         1.100         Norate blocked           VM 686         (0.100)         24K         (7.189)         (689)         (689)         (1.890)         (689)         (689)         (689)         (689)         (689)         (689)         (689) </td <td>XSR-22</td> <td>VM 581</td> <td>0.125</td> <td>24K</td> <td>3.125</td> <td>1160</td> <td>1430</td> <td>1160</td> <td>0</td> <td>No helium flow</td>	XSR-22	VM 581	0.125	24K	3.125	1160	1430	1160	0	No helium flow
VM 681         0.100         24K         3.125         1170         1480         1180         75.2           VM 682         0.1284         24K*         5.280         (82)         2600         0         Solidified           VM 682         0.128         24K*         5.280         2600         1280         7.48         Nozzle           VM 682         0.100         30K*         3.126         1180         1540         (82)         1480         1480         0         Nozzle           VM 683         0.126         24K         3.126         1180         1540         (82)         1480         1660         Nozzle           VM 683         0.126         24K         3.126         1180         1540         1880         0         Nozzle           VM 686         0.126         24K         3.126         1180         1380         1180         46.0         Nozzle           VM 686         0.126         24K         3.126         120         140         1180         16.0         16.0           VM 686         0.100         24K         3.126         120         140         10.0         Nozzle           VM 686         0.100         24K			(0.318)		(7.938)	(827)	(777)	(827)		
VM 582         (610)         (627) <t< td=""><td>XSR-23</td><td>VM 581</td><td>0.100</td><td>24K</td><td>3.125</td><td>1170</td><td>1480</td><td>1160</td><td>75.2</td><td></td></t<>	XSR-23	VM 581	0.100	24K	3.125	1170	1480	1160	75.2	
VM 682         0.125         24K¹         5.250         —         2620         2600         0         Solidified           VM 682         0.100         30K¹         13.386         (14.38)         (1427)         74.8         Nozzle           VM 682         0.100         24K¹         3.125         1180         (1427)         74.8         Nozzle           VM 683         0.1264         24K¹         3.125         1180         (1540)         1180         0         Nozzle blocked           VM 683         0.125         24K         3.125         1180         1360         1180         0         Nozzle blocked         0         Nozzle blocked </td <td></td> <td></td> <td>(0.254)</td> <td></td> <td>(7.938)</td> <td>(632)</td> <td>(810)</td> <td>(627)</td> <td></td> <td></td>			(0.254)		(7.938)	(632)	(810)	(627)		
VM 662         (0.100)         30K*         (14.38)         (14.29)         (14.27)         74.8           VM 662         (0.100)         24K*         (3.144)         (660)         (882)         —         74.8           VM 663         (0.100)         24K*         (3.144)         (660)         (882)         —         74.8           VM 663         (0.1054)         24K*         (7.889)         (689)         (1899)         (641)         0         Noarle blocked           VM 663         (0.1264)         24K         (7.889)         (689)         (1899)         (641)         460         Noarle blocked           VM 686         (0.126         24K         (7.889)         (689)         (732)         (639)         0         Noarle blocked           VM 686         (0.100)         24K         (7.889)         (689)         (732)         (639)         0         Noarle blocked           VM 686         (0.100)         24K         (7.889)         (689)         (732)         (689)         (732)         (789)         (789)         (732)         (789)         (789)         (732)         (732)         (732)         (732)         (732)         (732)         (732)         (732)         (733	XSR-24	VM 592	0.125	24K1	5.250	ŀ	2620	2800	0	Solidified in
VM 682         0.318)         (13.38)         (1427)         74.8           VM 682         0.264)         30K*         3.960         1220         (1830)         —         74.8           VM 682         0.100         24K*         3.126         1180         (641)         0         Norate blocked           VM 683         0.125         24K         3.126         1180         (641)         0         Norate blocked           VM 683         0.125         24K         3.126         1180         (681)         660         Norate blocked           VM 683         0.126         24K         3.125         1180         (732)         (683)         Norate blocked           VM 686         0.100         24K         3.125         120         1410         1180         7.2.7           VM 686         0.100         24K         3.126         1230         1410         1180         7.2.7           VM 686         0.100         24K         3.126         1230         1669         1830         1830           VM 686         0.100         24K         3.126         1230         1669         1830         1830           VM 686         0.100         24K										Nozzle
VM 682         0.100         30K¹         3.600         1220         1630         —         74.8           VM 682         0.100         24K¹         3.126         1180         (641)         0         Nozzle blocked           VM 683         0.125         24K         3.125         1180         (641)         460         Nozzle blocked           VM 683         0.125         24K         3.125         1180         (681)         668         0         Solidified           VM 683         0.125         24K         3.125         1180         (681)         0         Nozzle blocked           VM 686         0.126         24K         3.125         1210         1410         1180         72.7           VM 686         0.100         24K         3.125         1210         1400         1727         Nozzle blocked           VM 686         0.100         24K         3.125         120         1406         120         72.7           VM 686         0.100         24K         3.125         120         1406         120         72.7           VM 686         0.100         24K         3.125         120         1406         120         76.8			(0.318)		(13.335)		(1438)	(1427)		
VM 682         0.0264         (9.144)         (660)         (682)         (1836)         0.0264         Norzie bloched (641)           VM 683         0.126         24K         3.126         —         1510         1180         46.0         Norzie bloched (641)           VM 683         0.126         24K         3.126         —         1510         1180         46.0         Norzie bloched (641)           VM 683         0.126         24K         3.126         1180         1180         0         Solidified (641)           VM 686         0.100         24K         3.126         1290         1410         1180         72.7           VM 686         0.100         24K         3.126         1230         1410         1170         83.8           VM 686         0.100         24K         3.126         1230         140         76.8         83.8           VM 686         0.100         30K¹         3.60         1240         1664         1720         76.8           VM 696         0.100         36K¹         3.60         1240         1600         1140         13.0           VM 696         0.100         36K¹         3.60         1240         1600         14	XSR-25	VM 582	0.100	30K:	3.600	1220	1630	1	74.8	
VM 682         0.100         24K¹         3.125         1180         1540         1185         0         Noazle blocked           VM 683         0.1254         7.793         683         (1884)         (641)         661         0         Noazle blocked           VM 683         0.125         24K         3.125         1180         1380         1180         6.63         Noazle           VM 683         0.125         24K         3.126         11210         1410         1180         7.27           VM 686         0.100         24K         3.125         1210         1410         1180         72.7           VM 686         0.100         24K         3.125         1290         (689)         (639)         72.7           VM 696         0.100         24K         3.125         1290         1400         1170         83.8           VM 696         0.100         24K         3.126         1290         1669         6649         72.7           VM 696         0.100         24K         3.126         1290         1690         76.8           VM 696         0.100         24K         3.129         1690         76.8           VM 697			(0.254)		(9.144)	(099)	(837)			
VM 683         (0.254)         (7.938)         (638)         (1880)         (641)           VM 683         0.135         24K         3.125         —         1510         1180         46.0           VM 683         0.125         24K         3.125         —         1510         1180         0         Solidified           VM 686         0.100         24K         3.125         1210         1470         1180         72.7           VM 686         0.100         24K         3.125         1230         1480         1220         1783           VM 686         0.100         24K         3.125         1230         1486         1200         76.8           VM 686         0.100         24K         3.125         1230         1486         1200         76.8           VM 686         0.100         24K         3.125         1230         1486         1200         76.8           VM 686         0.100         30K¹         7.938         (666)         (618)         (623)         76.8           VM 696         0.100         30K¹         7.938         (666)         (818)         (623)         76.8           VM 697         0.100         30K¹	XSR-26	VM 582	0.100	24K1	3.125	1180	1540	1186	0	Nozzle blocked
VM 683         0.125         24K         3.125         —         1510         1180         46.0           VM 683         0.125         24K         3.125         —         1510         1180         0.6.0           VM 683         0.125         24K         3.125         1180         1732         (638)         0.024         Nozzle           VM 686         0.100         24K         3.125         1230         1410         1180         72.7           VM 686         0.100         24K         3.125         1230         1400         1870         78.8           VM 686         0.100         24K         3.126         1230         1406         1200         76.8           VM 686         0.100         30K         3.126         1230         1406         1200         76.8           VM 686         0.100         36K         3.126         1230         1606         1170         9.8           VM 687         0.100         36K         3.600         1240         1671         1680         1680         1680         1680         1680         1680         1680         1680         1680         1680         1680         1680         1680 <t< td=""><td></td><td></td><td>(0.254)</td><td></td><td>(7.938)</td><td>(838)</td><td>(1838)</td><td>(841)</td><td></td><td></td></t<>			(0.254)		(7.938)	(838)	(1838)	(841)		
VM 683         (0.316)         (7.938)         (7.938)         (821)         (638)         Nozzle           (0.316)         0.126         24K         3.126         1190         1360         1180         0         Solidified           VM 696         0.100         24K         3.126         1210         1410         1190         72.7         Nozzle	XSR-27	VM 583	0.125	24K	3.125		1510	1180	46.0	
VM 583         0.125         24K         3.126         1180         1360         1180         0         Solidified           (0.318)         (7.328)         (638)         (7.32)         (638)         72.7         Nozzle           VM 586         0.100         24K         3.125         12.90         1410         1180         72.7           VM 586         0.100         24K         3.125         12.90         1400         1170         83.8           VM 586         0.100         24K         3.125         12.90         1486         1200         78.8           VM 586         0.100         24K         3.125         12.40         1606         1170         83.8           VM 586         0.100         30K1         3.600         12.40         1606         1180/1180         78.8           VM 586         0.100         36K1         3.600         12.40         1606         1180/1180         1.3           VM 582         0.100         36K1         5.260         2400         2800         2860         5.0           VM 582         0.188         24K         5.260         2400         2800         2860         5.6           VM 584			(0.318)		(7.938)		(821)	(639)		
VM 596         0.0318)         (7.938)         (688)         (732)         (638)         72.7           VM 596         0.100         24K         3.125         1230         1410         1180         72.7           VM 596         0.100         24K         3.126         1230         1500         1170         83.8           VM 596         0.100         24K         3.126         1230         1496         1200         76.8           VM 596         0.100         24K         3.126         1230         1496         1200         76.8           VM 596         0.100         24K         3.400         1240         1606         1170         0           VM 696         0.100         36K¹         3.600         1240         1606         1170         0           VM 697         0.100         36K¹         3.600         1240         1600         1170         0           VM 698         0.169         24K         6.260         2400         3000         2860         5.60           VM 692         0.168         24K         6.260         2400         2900         2860         560           VM 698         0.168         24K         <	XSR-28	VM 583	0.125	24K	3.125	1180	1360	1180	0	Solidified in
(0.316)         (7.338)         (689)         (732)         (638)           (0.264)         (0.264)         (7.338)         (664)         (766)         (638)           VM 696         (0.100)         24K         3.125         1210         1410         1180         72.7           VM 696         (0.100)         24K         3.125         1230         1600         1170         83.8           VM 696         (0.264)         (7.938)         (666)         (616)         (632)         76.8           VM 696         (0.254)         3.125         1230         1496         1200         76.8           VM 696         (0.100)         30K¹         3.600         1240         (613)         (649)         6.13           VM 615         (0.254)         *         (9.144)         (671)         (818)         (627)         0           VM 615         (0.264)         *         (9.144)         (671)         (818)         (627)         0           VM 616         (0.254)         *         (9.144)         (671)         (818)         (627)         0           VM 617         (0.254)         240         2400         3000         2400         2400 <t< td=""><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>Nozzle</td></t<>										Nozzle
VM 696         0.100         24K         3.125         1210         1410         1180         72.7           VM 696         0.100         24K         3.125         1230         (168)         (683)           VM 696         0.100         24K         3.125         1230         (1406)         (683)           VM 696         0.100         24K         3.126         1230         1496         1200         76.8           VM 696         0.100         30K¹         3.800         1240         (613)         (649)         76.8           VM 615         0.100         30K¹         3.800         1240         1606         1170         0           VM 615         0.100         36K¹         3.600         1240         (671)         (818)         (649)         0           VM 615         0.100         36K¹         3.600         1240         1500         1180/1180         62.7643         0           VM 616         0.100         36K²         3.600         1240         (671)         (818)         (627/643)         0           VM 62         0.158         24K         5.250         2400         2900         2860         >50           VM 69			(0.318)		(7.938)	(889)	(732)	(638)		
VM 566         (0.254)         (7.938)         (664)         (766)         (638)           VM 566         0.100         24K         3.125         1230         1500         1170         83.8           VM 566         0.100         24K         3.125         1230         1496         1200         76.8           VM 566         0.100         24K         3.125         1230         1496         1200         76.8           VM 566         0.100         30K¹         3.600         1240         1606         1170         0           VM 615         0.100         30K¹         3.600         1240         1606         1180/1190         51.3           VM 615         0.100         36K¹         3.600         1240         1606         1180/1190         51.3           VM 615         0.168         24K         5.260         2400         3000         2860         50           VM 582         0.168         24K         5.260         2400         2900         2860         50           VM 583         0.168         24K         5.250         2400         2900         2860         56           VM 694         0.169         24K         5.250 </td <td>XSR-29</td> <td>VM 696</td> <td>0.100</td> <td>24K</td> <td>3.125</td> <td>1210</td> <td>1410</td> <td>1180</td> <td>72.7</td> <td></td>	XSR-29	VM 696	0.100	24K	3.125	1210	1410	1180	72.7	
VM 696         0.100         24K         3.125         1230         1500         1170         83.8           (0.254)         (7.938)         (666)         (616)         (632)         76.8           VM 696         0.100         24K         3.256         1230         1495         1200         76.8           VM 696         0.100         30K¹         3.600         1240         1606         1170         0           VM 615         0.100         30K¹         3.600         1240         1606         1170         0           VM 615         0.100         36K¹         3.600         1240         1606         1180/1190         51.3           VM 615         0.100         36K¹         3.600         1240         1606         1180/1190         51.3           VM 622         0.168         24K         5.250         2400         3000         2860         0           VM 692         0.168         24K         5.250         2400         3000         2860         >50           VM 692         0.168         24K         5.250         2400         2900         2460         >50           VM 694         0.169         24K         5.250			(0.254)		(7.938)	(654)	(186)	(838)		
VM 696         (616)         (632)         76.8           VM 696         0.100         24K         3.126         1230         1496         1200         76.8           VM 696         0.100         30K¹         3.600         1240         1605         1170         0           VM 696         0.100         30K¹         3.600         1240         1605         1170         0           VM 615         0.100         36K¹         3.600         1240         1605         1160/1190         61.3           VM 615         0.100         36K¹         3.600         1240         1600         1160/1190         61.3           VM 615         0.169         24K         6.250         2400         3000         2850         0           VM 692         0.168         24K         6.250         2400         2900         2460         560           VM 692         0.168         24K         6.250         2400         2900         2460         560           VM 693         0.168         24K         6.250         2450         2900         2460         560           VM 694         0.169         24K         6.250         2250         2900	XSR-30	VM 596	0.100	24K	3.125	1230	1500	1170	83.8	
VM 696         0.100         24K         3.126         1230         1496         1200         76.8           0.254)         (7.538)         (666)         (613)         (649)         0.0 <td></td> <td></td> <td>(0.254)</td> <td></td> <td>(7.938)</td> <td>(999)</td> <td>(818)</td> <td>(632)</td> <td></td> <td></td>			(0.254)		(7.938)	(999)	(818)	(632)		
VM 696         (613)         (649)           VM 696         0.100         30K¹         3.600         1240         1606         1170         0           VM 615         0.100         36K¹         3.600         1240         1606         1170         0           VM 615         0.100         35K¹         3.600         1240         1600         1180/1190         61.3           VM 615         0.100         36K¹         3.600         1240         1600         1180/1190         61.3           VM 692         0.168         24K         6.260         2400         2900         2860         >60           VM 692         0.168         24K         6.260         2400         2900         2860         >60           VM 693         0.168         24K         6.260         2400         2900         2860         >60           VM 693         0.168         24K         6.260         2460         2900         2860         >60           VM 694         0.169         24K         6.260         2460         2900         2860         >60           VM 694         0.169         24K         6.260         2900         2860         >60     <	XSR-31	VM 596	0.100	24K	3.125	1230	1496	1200	76.8	
VM 566         0.100         30K¹         3.600         1240         1606         1170         0           (0.254)         (9.144)         (671)         (618)         (632)         0           VM 615         (0.254)         *         (9.144)         (671)         (616)         (1632)           VM 616         (0.254)         *         (9.144)         (671)         (616)         (624)         61.33           VM 692         0.158         24K         5.250         2400         2900         2860         > 50           VM 682         0.158         24K         5.250         2400         2900         2860         > 50           VM 683         0.158         24K         5.250         2400         2900         2860         > 50           VM 684         0.158         24K         5.250         2450         2900         2860         > 50           VM 694         0.168         24K         6.250         2360         2860         > 50           VM 694         0.168         24K         6.250         2360         2860         > 50           VM 691         0.401         0.168         24K         6.250         2900         2860			(0.254)	į	(7.938)	(999)	(813)	(848)		
VM 615         (0.254)         (9.144)         (671)         (618)         (632)           VM 615         0.100         35K¹         3.600         1240         1160         1160/1190         61.3           VM 692         0.168         24K         5.260         2400         3000         2660         0           VM 692         0.169         24K         5.260         2400         2800         2660         >60           VM 692         0.169         24K         5.260         2400         2800         2860         >60           VM 683         0.169         24K         5.260         2460         2800         2860         >60           VM 683         0.169         24K         6.260         2460         2800         2860         >60           VM 694         0.169         24K         6.260         2460         2800         2860         >60           VM 694         0.169         24K         6.260         2360         2800         2860         >60           VM 691         0.401         (13.336)         (1289)         (1464)         >60         >60           VM 691         0.169         24K         5.260         2360 <td>XSR-32</td> <td>VM 596</td> <td>0.100</td> <td>30K;</td> <td>3.600</td> <td>1240</td> <td>1506</td> <td>1170</td> <td>0</td> <td>Stopper rod</td>	XSR-32	VM 596	0.100	30K;	3.600	1240	1506	1170	0	Stopper rod
VM 615         0.100         35K¹         3.600         1240         1600         1160/1190         61.3           0.254)         *         (9.144)         (671)         (616)         (626)         6.254         0           0 VM 692         0.158         24K         6.260         2400         3000         2860         0           0 VM 692         0.158         24K         6.260         2400         2800         2860         >60           0 VM 683         0.158         24K         6.260         2460         2800         2860         >60           0 VM 683         0.158         24K         6.250         2450         2900         2860         >60           0 VM 684         0.168         24K         6.250         2450         2900         2860         >60           0 VM 694         0.169         24K         6.250         2360         2800         >60           1 VM 694         0.169         24K         6.250         2360         2800         >60           1 VM 691         0.401         (13.336)         (1289)         (1464)         (1464)           1 VM 691         0.169         24K         5.260         2360	1		(0.254)		(9.144)	(671)	(818)	(632)		did not release
VM 592 (0.254) (671) (616) (627/643) (677/643)	XSR-33	VM 615	0.100	36K	3.600	1240	1500	1160/1190	51.3	
VM 592 0.158 24K 5.250 2400 3000 2850 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0			(0.254)	• ;	(9.144)	(671)	(816)	(627/643)		
(0.401)         (13.335)         (1316)         (1649)         (1454)           VM 592         0.158         24K         5.250         2400         2900         2850         >50           (0.401)         (13.336)         (1316)         (1683)         (1464)         >50           VM 594         0.158         24K         5.250         2360         >60           VM 594         0.156         24K         5.250         2360         >60           VM 591         0.158         24K         5.250         2360         >60           VM 591         0.168         24K         5.250         2360         >60           VM 591         0.168         24K         5.250         2360         >60           (0.401)         (13.335)         (1286)         (1683)         (1464)         >60           (0.401)         (13.336)         (1288)         (1683)         (1464)         >60	RSR-199	VM 592	0.168	24K	5.250	2400	900	2860	0	Nozzle plugged
VM 592 0.168 24K 5.250 2400 2900 2860 (1464) (13.35) (1316) (1583) (1464) (1464) (1683) (1464) (1683) (1464) (1683) (1464) (1683) (1464) (1683) (1464) (1683) (1683) (1464) (1884) (1884) (1883) (1464) (1884) (1883) (1883) (1464) (1883) (1883) (1883) (1464) (1883) (1883) (1464) (1883) (1883) (1464) (1883) (1464) (1883) (1883) (1464)			(0.401	;	(13.335)	(1316)	(1649)	(1454)		
VM 583         (0.401)         (13.335)         (1316)         (1563)         (1464)           VM 583         0.158         24K         5.250         2450         2900         2860           (0.401)         (13.335)         (1343)         (1563)         (1464)           (0.401)         (13.335)         (1286)         (1583)         (1464)           (0.401)         (13.335)         (1289)         (1583)         (1464)           (0.401)         (13.335)         (1289)         (1539)         (1464)	RSR-200	VM 592	0.158	24K	5.250	2400	2800	2860	\$ \$	
VM 583 0.158 24K 5.250 2450 2900 2860 260 (1464) (13.35) (13.43) (1583) (1464) (1464) (14.64) (16.40) (16.401) (16.250 2350 2360 2860 (16.401) (16.250 2350 2360 2360 (16.464) (16.401) (13.35) (12.88) (16.93) (14.64) (16.401) (13.335) (12.88) (16.38) (14.64)			(0.401)		(13.335)	(1316)	(1583)	(1464)		
(0.401) (13.335) (1343) (1563) (1464) (1464) (1563) (1464) (1663) (1464) (1663) (1664)	RSR-201	VM 593	0.158	24K	5.250	2450	2800	2660	\$ \$	
VM 594 0.158 24K 5.250 2350 2900 2850 (1454) (1454) (1593) (1454) (1583) (1583) (1454) (1454) (1581) (1583) (1454) (1454) (1454) (1581) (1581) (1583) (1583) (1454)			(0.401)		(13.335)	(1343)	(1983)	(1464)		
(0.401) (13.335) (1288) (1663) (1464) (1464) (1691) (1693) (1464) (1691) (1691) (1692) (1692) (1692) (1693) (1693) (1694) (1694)	RSR-202	VM 594	0.158	24K	5.250	2360	2800	2860	26 \	
VM 591 0.168 24K 5.250 2350 2800 2860 (1.454) (1.401) (1.401) (1.3.335) (1.288) (1.539) (1.454)			(0.401)		(13.335)	(1288)	(1993)	(1454)		
(0.401) (13.335) (1288) (1639) (1464)	RSR-203	VM 591	0.158	24K	5.250	2350	2800	2860	<b>26</b>	
			(0.401)		(13.335)	(1288)	(1538)	(1454)		

<sup>\*</sup>Bearing failure caused speed decay from initial 35K to zero during run, accounting for poor yield of -140 mesh powder. \*35K turbine run at indicated rpm.
\*Percent yield-wt of -140 mesh/wt charged.

TABLE 4. COMPOSITION OF ALLOYS CONVERTED TO POWDER\*

Powder Run No.	VM No.	Zn	Co	Al	Mg	Cu	Cr	Mo	C	V	Fe
XSR 19 (7075)	578	5.6		Bal.	2.5	1.6	0.3				
XSR 20 (7075)	578	5.6	_	Bai.	2.5	1.6	0.3				
XSR 21 (7075)	578	5.6	_	Bal.	2.5	1.6	0.3				
XSR 22	581	5.6	0.8	Bal.	2.5	1.0					
XSR 23	581	5.6	0.8	Bal.	2.5	1.0					
XSR 24	5 <b>92</b>						14.0	6.0	1.1	1.0	Bal.
XSR 25	582	5.6	1.6	Bal.	2.5	1.0					
XSR 26	582	5.6	1.6	Bal.	2.5	1.0					
XSR 27	583	5.6	3.2	Bal.	2.5	1.0					
XSR 28	583	5.6	3.2	Bal.	2.5	1.0					
XSR 29	595	7.0	0.8	Bal.	2.5	1.0					
XSR 30	596	7.0	0.8	Bal.	2.5	1.0					
XSR 31	595	7.0	0.8	Bal.	2.5	1.0					
XSR 32	596	7.0	3.2	Bal.	2.5	1.0					
XSR 33	615	7.0	3.2	Bal.	2.5	1.0					
RSR 199	592						14.0	6.0	1.0	1.0	Bal.
RSR 200	592						14.0	6.0	1.1	1.0	Bal.
RSR 201	593						19.0	2	1.25	1.0	Bal.
RSR 202	594						19.0	8	1.25	1.0	Bal.
RSR 203	591						14.0	2	1.1	i	Bal.

TABLE 5. IRON ALLOY EXTRUSIONS

Identification No.	Extrusion *F	Tonnage*	
200A	1850	(1010)	500
201A	1850F	(1010)	500
202A	1850	(1010)	510
203A	1850	(1010)	475
200B	2000	(1093)	600
201B	2000	(1093)	450
202B	2000	(1093)	430
203B	2000	(1093)	400
200C	1750	(954)	540
201C	1750	(954)	500
202C	1750	(954)	570
203C	1750	(954)	560

\*Breakthrough pressure

#### **SECTION V**

#### **MATERIAL EVALUATION**

#### **ALUMINUM ALLOYS**

Due to difficulty encountered in producing Al buttons only one sample B1 was treated by electron beam (EB) surface irradiation. This sample was given six different weld passes. Weld depths ranged from 0.03 in. (0.08 cm) to 0.053 in. (0.13 cm). Additional effort in this area will be provided using the induction furnace for melting and EB welding at lower power settings to produce shallower penetration and resulting faster cooling. Figure 5 shows a representative weld and resulting microstructure.

Examination of XSR Al powder revealed a rough surface as compared to RSR Al powder shown in Figure 6. The rough surface on XSR powder is due to a smaller chamber and multiple collisions with chamber walls and other powder particles. Microscopic examination of powder cross-section revealed a two-phase structure which can be described as cellular. Powder produced in the RSR rig is, as expected, very similar microstructurally to XSR Al powder. (See Figures 7 and 8.)

#### **IRON ALLOYS**

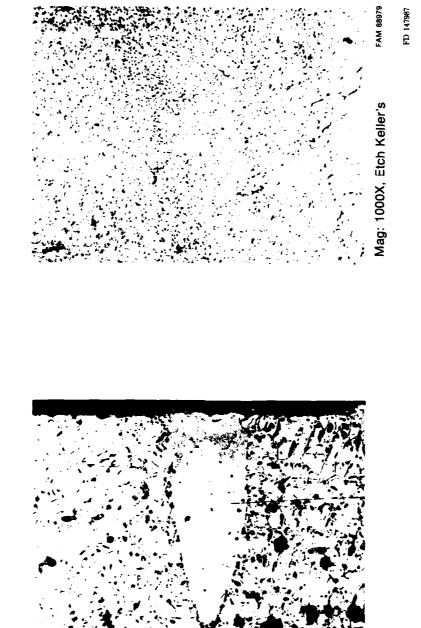
EB weld parameters were varied to produce different levels of penetration in iron alloy samples. Penetration varied from approximately 0.004 in. (0.010 cm) to 0.010 in. (0.025 cm), and machine parameters producing weld penetration of 0.004 in. (0.010 cm) and 0.008 in. (0.020 cm) were selected for welding of all iron alloys. Figure 9 shows representative structures resulting from EB welding using the selected penetration levels. Hardness readings were taken on buttons BI-2 through 10 and BI 16-19 and are presented in Table 6. Buttons 16-18A were given a solution cycle of 2050°F (1121°C) for 10 minutes followed by an oil quench. Hardness measurements were taken and are also presented in Table 6. Hardness obtained on 16-18A, R<sub>c</sub> 61.5-64.2, were comparable to hardnesses obtained on heat treated extrusions from RSR powder. Future effort will be directed toward heat treatment of selected buttons from Table 6 and melting additional alloys with compositional variations over a wider range than those examined in this quarter.

Examination of iron alloy powder particles revealed an occasional cellular structure and a predominantly fine structure which could not be classed as either cellular or dendrite. (See Figure 10.)

Iron alloy extrusions were examined metallographically and found to have a uniform structure with a fine carbide dispersion and a grain size of ASTM 9-11 or smaller. Figure 11 shows representative structures of 202C and 203B.

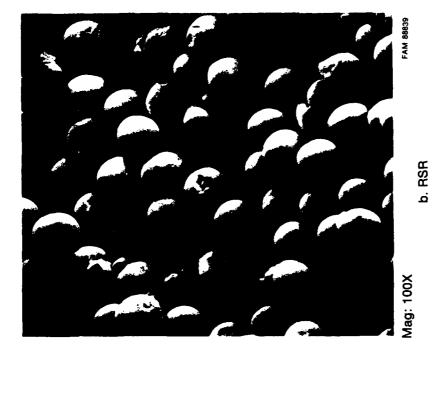
Extrusions were cut up and the sections stamped with identification numbers. The sections were then heat treated and hardness readings taken. The identification scheme used and particulars of various heat treatments are given in Table 7. Figure 12 shows a representative structure of a steel alloy which has been solutioned at 2100°F (1148°C) for 10 minutes and quenched, note uniform carbide dispersion.

All samples were quenched into a salt brine dry ice mixture from the solution temperature, surface ground to remove de-carburized layer and hardness readings taken. Table 8 lists the hardness readings obtained.



ii ii

Figure 5. B-1, EB Weld No. 4, Penetration 0.046 in. (0.117 cm)



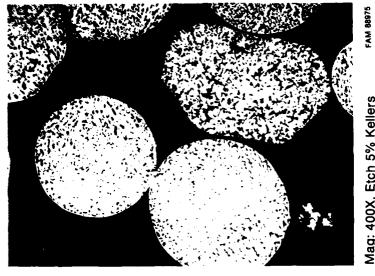
日本 交通

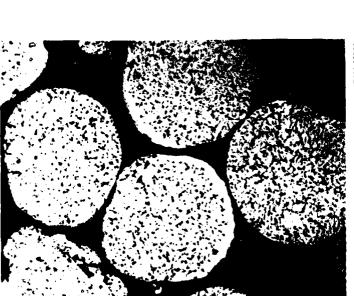


Figure 6. Surface Appearance of 90 µm XSR and RSR 7075 Aluminum Powder

a. XSR

FD 147988





Mag: 400X, Etch 20% Keller's FAM 88968 XSR-19

Mag: 400X, Etch 5% Kellers RSR

FD 147989

Figure 7. Microstructure of 90 µm XSR and RSR 7075 Aluminum Powder

**10**00 000

**■ 200 ■ 100 BOO** 

. .

.

Figure 8. Microstructure of 62 µm XSR and RSR 7075 Aluminum Powder

Mag: 1000X

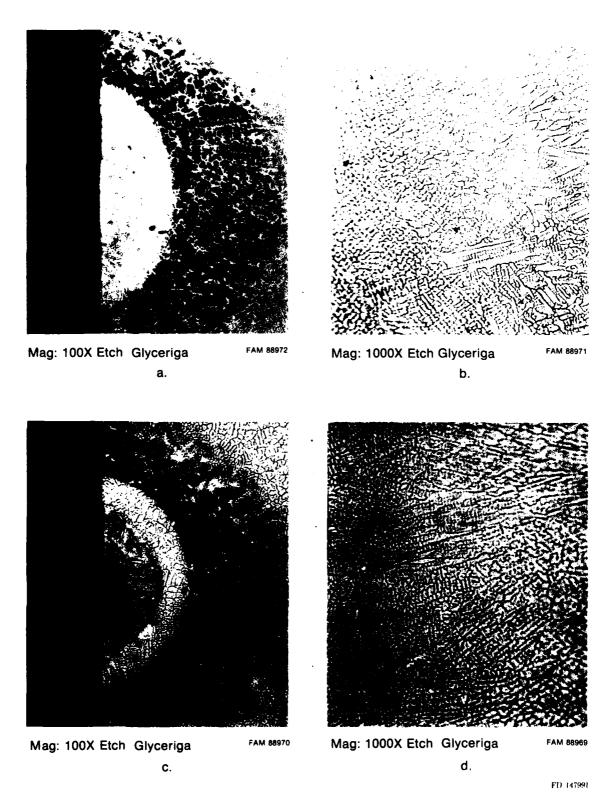


Figure 9. Representative Microstructure of Iron Alloy Buttons, as EB Welded: a and b Penetration of 0.004 in. (0.010 cm); c and d Penetration of 0.008 in. (0.020 cm).

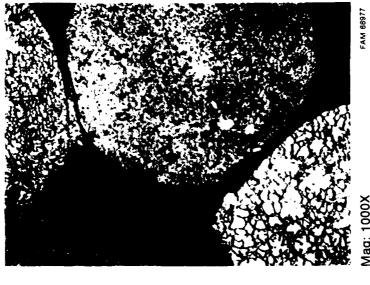
TABLE 6. IRON ALLOY BUTTON HARDNESS<sup>1</sup>

I.D. No.	No. 1 Weld <sup>a</sup>	No. 1 Weld (HT)	No. 2 Weld³	No. 2 Weld (HT)
BI-2	62		63	
3	64		62	
4	58		57	
5	50		47	
6	49		47	
7	53		45	
8	38		39	
9	45		46	
10	41		42	
16A	44	62	41	62
16 <b>B</b>	46		45	
17 <b>A</b>	48	61.5	45	62.5
17 <b>B</b>	42		44	
18A	46	63.5	47	64.2
18 <b>B</b>	_		_	
19A	81R <sub>b</sub>			
19B	44		44	

All hardnesses are R<sub>c</sub> unless otherwise indicated.

Weld No. 1 penetration approximately 0.004 in. (0.010 cm).

Weld No. 2 penetration approximately 0.008 in. (0.020 cm).



Mag: 1000X

FAM 88976

Mag: 400X

FD 147992

-140 Mesh Etch Glyceriga

Figure 10. Microstructure of RSR 200 Iron Alloy Powder

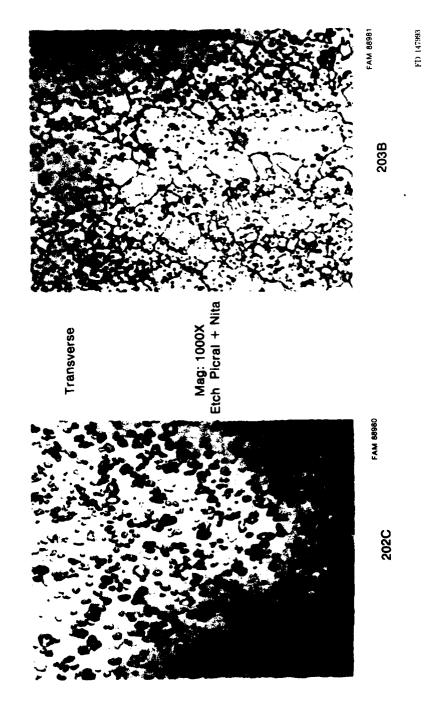


Figure 11. Representative Microstructure of Iron Alloy Extrusions

TABLE 7. FIRST IRON MATRIX EXTRUSION AND HEAT TREAT IDENTIFICATION SCHEME

Matrix No.	VM No.	RSR No.	Extrusion No.
9	591	203	3
10	592	199 + 200	0
14	593	201	1
15	594	202	2
Extrusion	Temp. (°F	/°C) <u>Ideni</u>	ification
185	60/1010		A
200	00/1093		B
178	1750/954		C
Solution To	emp.1 (°F/	°C) <u>Identi</u>	fication No.
180	00/982		8
	0/1038		9
	0/1093		0
	0/1148		1
	0/1204		2
	0/1260 0/1216		3
240	0/1316		4
Solution Tim	<u>e</u>	Ident	ification No.
			1
5 min.			
5 min. 10			2
			2 3

Example: Sample No. 3B14; 3- RSR 203, B-2000°F (1093°C) extrusion, 1- 2100°F (1148°C) solution, 4- 100 min solution

All samples were quenched in a salt brine/dry ice bath.

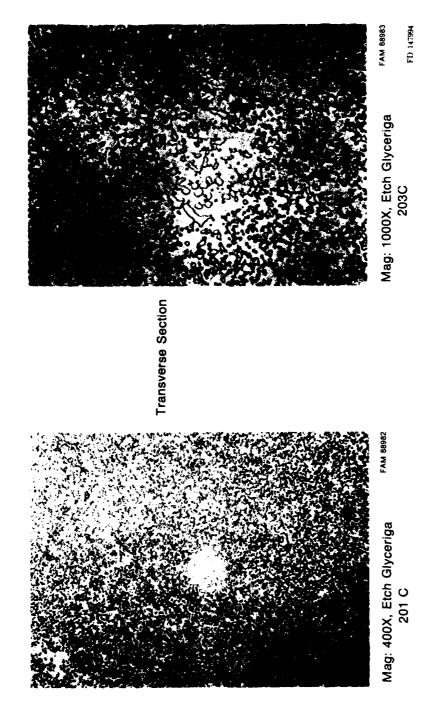


Figure 12. Representative Microstructures of Iron Alloy Extrusions, Solutioned and Quenched

TABLE 8. HARDNESS OF AS SOLUTIONED STEEL

Sample No.	Rc	Sample No.	Rc	Sample No.	Rc	Sample No.	Rc
OA81	_	1A81	31	2A81	_	3 <b>A</b> 81	49
82	44.7	82	43.9	82	31	82	<b>55</b> .3
83	51	83	54	83	17	83	57
84	34	84	50	84	27.5	84	46.5
OA91	51.5	1 <b>A9</b> 1	53	2A91	32	3 <b>A</b> 91	58.6
92	59.4	92	57.4	92	32	92	60
93	57	93	58.5	93	25.5	93	57
94	56.8	94	59	94	24	94	58
OA01	53.5	1A01	57.5	2A01	32	3A01	60
02	59.6	02	59.3	02	32.4	02	60.3
03	60	03	58.2	03	21.8	03	36.5
04	39	04	59.4	04	28.6	.04	46
OA11	56.4	1A11	61	2A11	31.7	3 <b>A</b> 11	61
12	60	12	<b>6</b> 0,5	12	29	12	61.1
13	61	13	59	13	29.2	13	34
14	32.5	14	61	14	29.5	14	49
OA21	58.9	1A21	56.5	2A21	29.5	3 <b>A</b> 21	53.5
22	42.5	22	50.5	22	29.5	22	40.5
23	28	23	47	23	31	23	39.8
24	30	24 24	40.5	24			
	30		90.0		32.5	24	38
OB81		1 <b>B</b> 81	36.8	2B81	_	3B81	47.1
82	44.1	82	45.4	82		82	54.6
83	50.5	83	53	83	27	83	57
84	31	84	24.5	84	26.5	84	52
OB91	54	1 <b>B9</b> 1	54	2 <b>B</b> 91	29.4	3 <b>B9</b> 1	57
92	<b>59.8</b>	92	57.2	92	24.7	92	58
93	57	93	58	93	27	93	56
94	57.5	94	51	94	28	94	56.5
OB01	55	1 <b>B</b> 01	56.8	2B01	29.8	3B01	60
02	58.5	02	58.6	02	30	02	60.1
03	58.7	03	60.5	03			
					27	03	50
04	60	04	59	04	26	04	58
OB11	59.8	1 <b>B</b> 11	61.5	2 <b>B</b> 11	28.8	3 <b>B</b> 11	62
12	60	12	60.4	12	25.5	12	59.8
13	59	13	60.4	13	27	13	21.7
14	41	14	59	14	23	14	20
OB21	53.5	1 <b>B</b> 21	58.5	2 <b>B</b> 21	28.3	3 <b>B</b> 21	52
22	41.5	22	46	22	33.5	22	41
23	24.5	23	44	23	22.3	23	32
24	31.5	24	39.5	24	35	24	17
OC81		1C81	31	2C81	27.5	3C81	46.4
82	45	82	44	82	28.9	82	55.1
83	51	83					
			54	83	23.5	83	57
84	35	84	33	84	24.5	84	53.5
OC91	53	1C91	53.8	2C91	29.2	3C91	57
92	58.1	92	57.7	92	30.1	92	60.4
93	54	93	57.5	93	27	93	58
94	35	94	58	94	27.7	94	58
OC01	53.8	1C01	59.2	2C01	28.2	3C01	54.7
02	60	02	58	02	31.1	02	60.3
03	60	03	59	03	27.3	03	61
04	45	04	5 <del>9</del> .5	04	28.5	04	60
OC11	58	1C11	61.5	2C11	29.5 29	3C11	60
12	61	12	59	12	29	12	59
13	<b>59</b> .5	13	59	13	28.2	13	57
14	52	14	59	14	41	14	59
OC21	54	1C21	<b>58</b> .5	2C21	28	3C21	56
22	_	22	41.5	22	32	22	41
23	21	23	46.5	23	25	23	36
24	31.5	24	13	24	33	24	

From this data, plots were made of hardness vs solution temperature with varying solution times using the two alloys, 201 and 203. Figures 13 and 14 show these results. Alloy 203 reached the highest hardness using solution temperature of  $2050^{\circ}F$  (1121°C) for ten minutes, with a maximum hardness attained of 61.1  $R_c$  in the solutioned and quenched state.

Several samples of Alloy 203C were given a heat treatment developed by Marlin-Rockwell Corporation (MRC) a division of TRW, for EX-00007, under contract by P&WA. The full heat treatment used was as follows:

1550°F/15 min $\rightarrow$ 2050°F/10 min/oil quench to black heat then air cool 350°F/2 hr/AC LN<sub>2</sub>/2 hr/to room temp. 950°F/3 hr/AC LN<sub>2</sub>/2 hr/to room temp. 950°F/3 hr/AC LN<sub>2</sub>/2 hr/to room temp. 950°F/3 hr/AC LN<sub>2</sub>/2 hr/to room temp.

Fully heat treated hardness on 203C was R<sub>c</sub> 61.3 as compared to 62.4 for EX-00007 heat treated by MRC! Typical microstructure of 203 CFHT, fully heat treated, is shown in Figure 15.

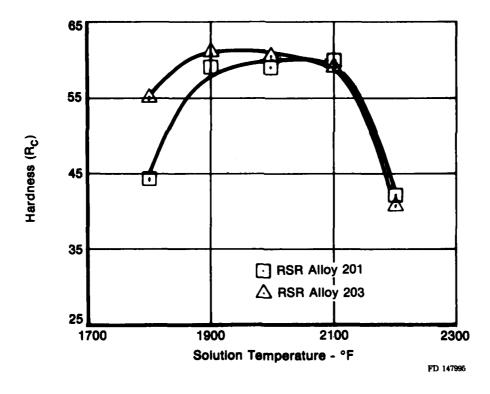
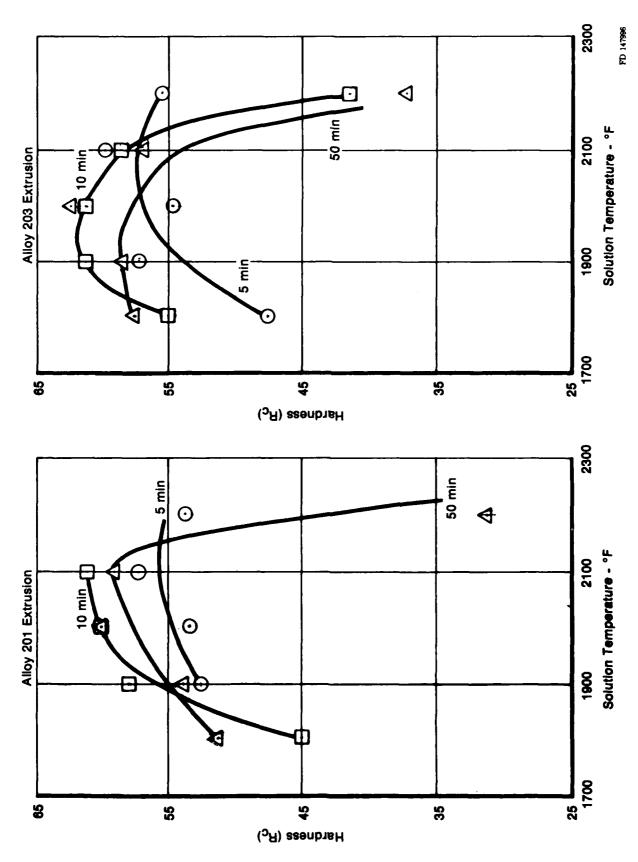


Figure 13. As Quenched Hardness vs 10 Min Solution Temperature

<sup>&</sup>lt;sup>1</sup> Brown, P. F., J. R. Potts, "Evaluation of Powder Processed Ball Bearings," Report No. AFAPL-TR-77-26.



ACCUSED COMMENCE DISTANCE DISTANCED CONTROL CO

Figure 14. Hardness vs Solution Temperature

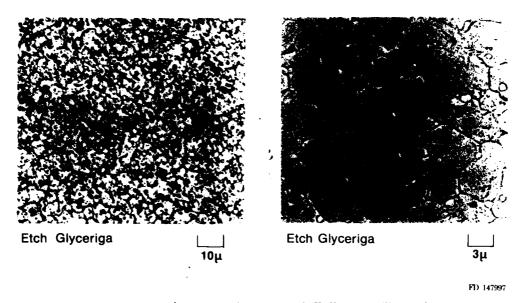


Figure 15. Typical Microstructure of Alloy 203C Fully Heat Treated

### **SECTION VI**

#### **ON-GOING STUDY**

Twelve aluminum extrusions will be done at AFML using an approximate extrusion ratio of 15:1 at temperatures ranging from 700 to 800°F (371 to 427°C). Microstructural evaluation will begin on this material upon receipt from AFML. Additional aluminum powder conversions will be attempted and the first run of the redesigned high-temperature furnace (steel conversion) will be made. Additional evaluation will be made on both aluminum and iron experimental samples, produced during this report period.

T

Diri